



Fermi National Accelerator Laboratory

3D simulations of the Lambertson magnets for the NOvA Experiment

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1 Introduction

The MLAW is a planned modification of existing MLA magnets for the accelerator upgrades planned for the NOvA experiment. In the NOvA era, the Recycler will change from being an Antiproton storage ring to being a Proton pre-injection ring for the Main Injector. One MLAW will be used in a new proton injection line from the existing MI-8 line into the Recycler. Another MLAW will be used in a new transfer line for extraction from the Recycler into Main Injector [1-2].

Currently, the MLA (referred in this note as Old) is used for injection into Main Injector (from the MI-8 line). It runs at approximately 950 A and provides an approximately 35 mrad bend. Only a 14 mrad bend will be required of the MLAW.

The MLAW (referred in this note as New) will run at approximately 430 A and a slightly larger gap. Figure 1 shows the cross section of this magnet.

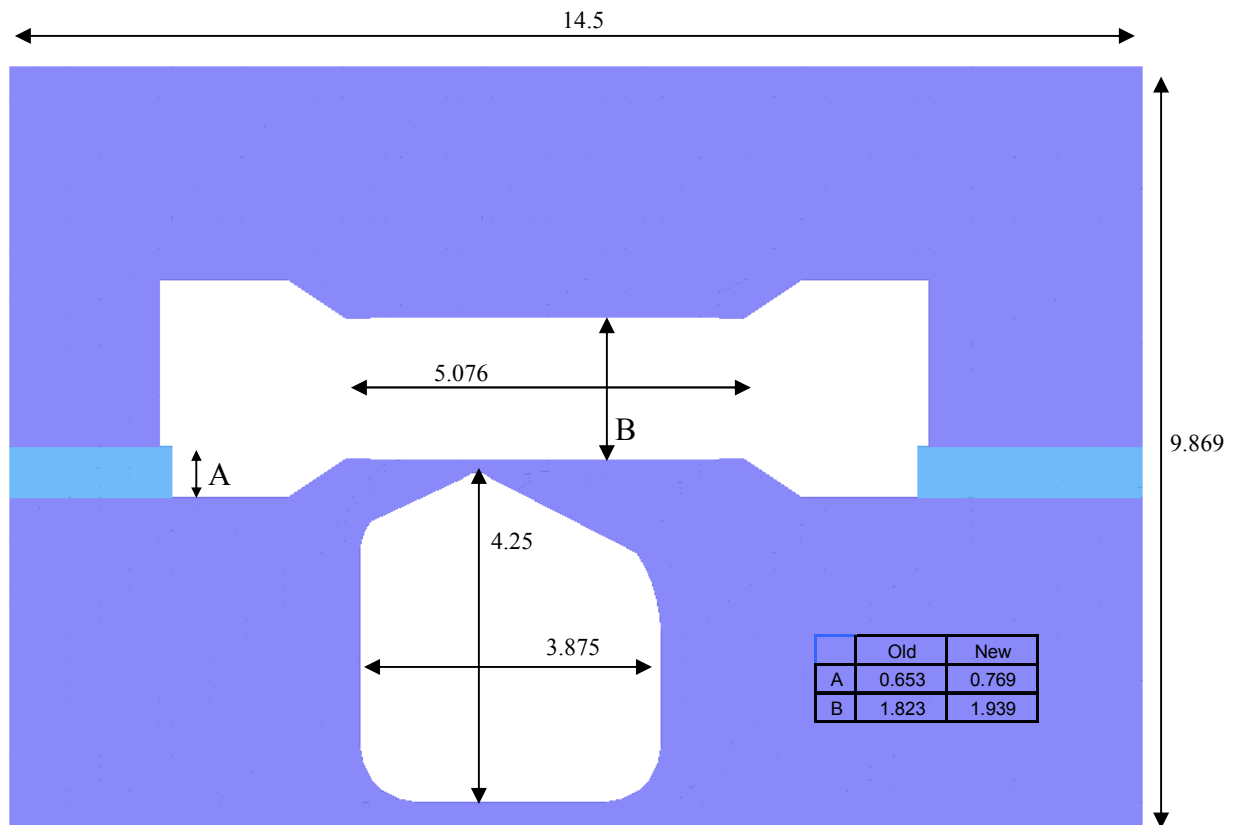


Figure 1 - Cross section (in inches).

The magnet is 90 inches long in the upper half and 106 inches in the lower half. Due to the symmetry of this magnet only half of the magnet was simulated (45 inches upper half and 53 inches lower half)

Two models were implemented in OPERA 3D using the correspondent currents operating currents. The data analysis is divided in the inter-pole and field-free regions.

2 Inter pole region

2.1 Longitudinal

Figure 2 shows the vertical field component (B_y) as function of the longitudinal axis (z) for the both cases. The only difference between the two simulated models is the gap which is around 18% larger in the new case. However the magnet current is about 55% lower.

The increment in the gap will direct affect the effective length of the magnet. The effective length is defined by:

$$L_{eff} = \frac{\int_{-\infty}^{+\infty} B_y(z) dz}{B_y(z=0)}$$

The calculated effective lengths were:

OLD: 92.4 inches
NEW: 92.5 inches

Therefore, comparing the two cases the increment of the effective length is about 2.5 mm (which corresponds to a 0.1 % difference).

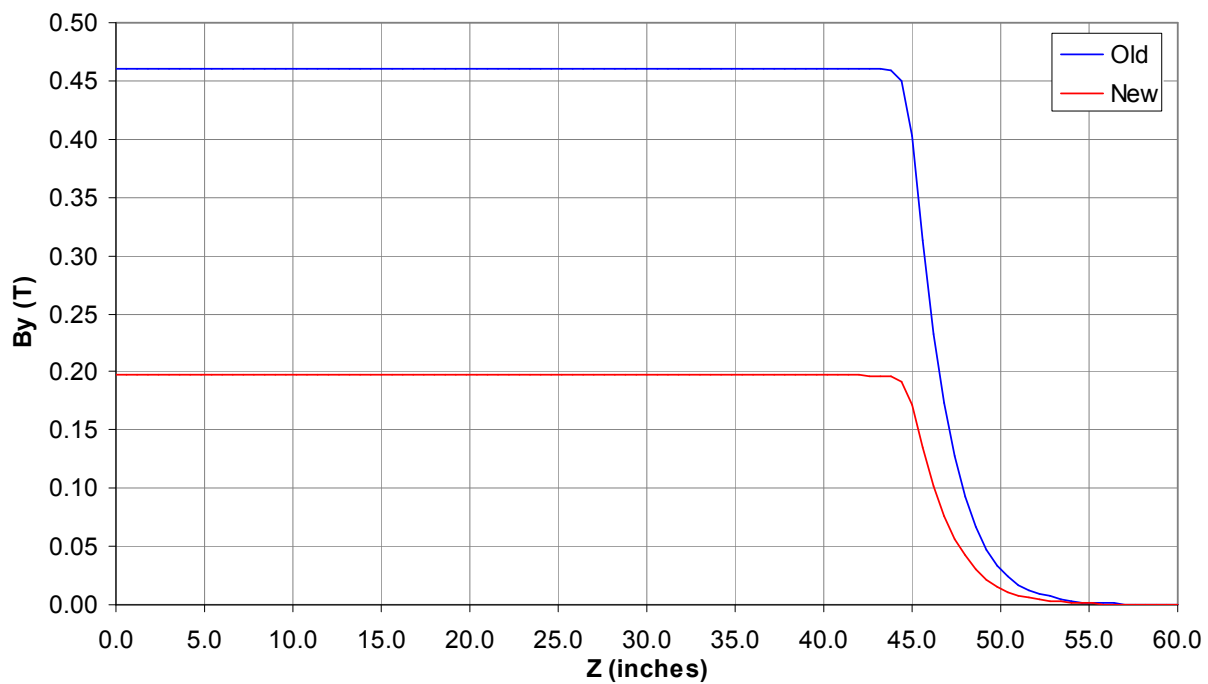


Figure 2 - B_y field component distribution along the longitudinal axis.

The change of the effective length can be barely seen when the data from Figure 2 is presented using the normalized field (Figure 3).

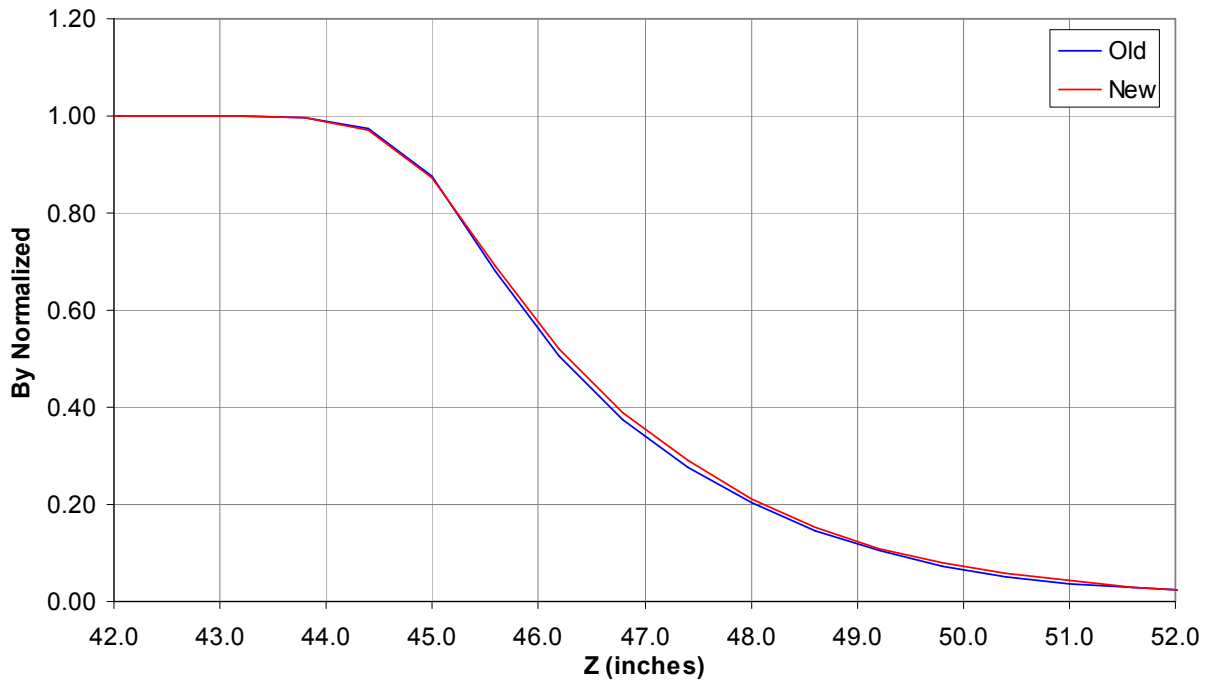


Figure 3 - Normalized By field component distribution along the longitudinal axis.

2.2 Transverse

The gap increment could also modify the transverse field uniformity because the shims used to optimize the field quality are designed for a fixed gap length. However the uniformity could be affected by the saturation of the iron. Figure 4 shows the field uniformity as function of the transverse position (x). As can be seen, the change in the field uniformity is minimum and mainly associate with the change in the gap (shims).

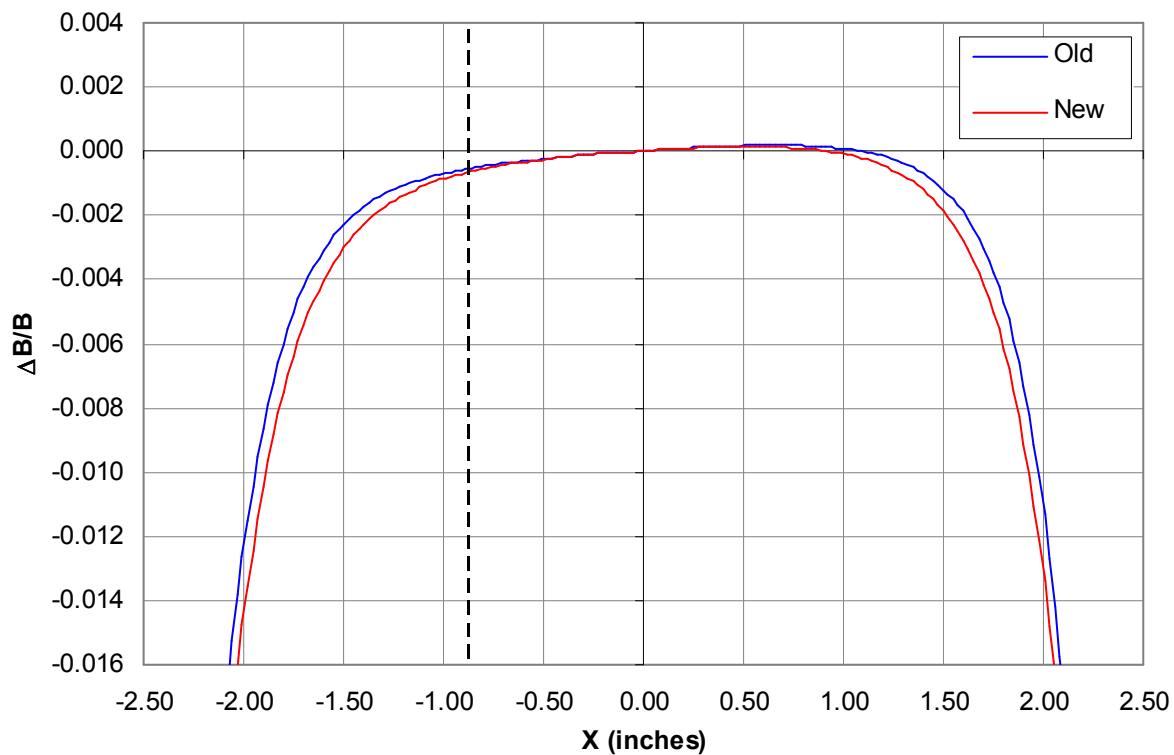


Figure 4 - Field uniformity distribution along the transverse position in the center of the magnet. The dashed line indicates the center of the field-free chamber and the horizontal limits of the pictures correspond to the whole pole region.

3 Field free region

3.1 Longitudinal

The field-free region, by definition, is the region with field (transverse components) near zero. Figure 5 shows the total field distribution on the surface of a cylinder surrounding the location of the circulating beam. As can be seen, the field is very low everywhere but near the open space. However the field in this region is only a function of the current (for the level of gap increment we are treating in here).

Figure 6-9 show, respectively, the B_y and B_x field components distribution along z and their magnifications in the central part of the cylinder seen on Figure 5.

If one calculates the integral of each individual component and each individual case, we observe a reduction in the new case:

	OLD	NEW
IBx (T.inches)	0.017026	0.009214
IBy (T.inches)	0.018395	0.007442

$\Delta IBx = 45.9\%$
 $\Delta IBy = 59.5\%$

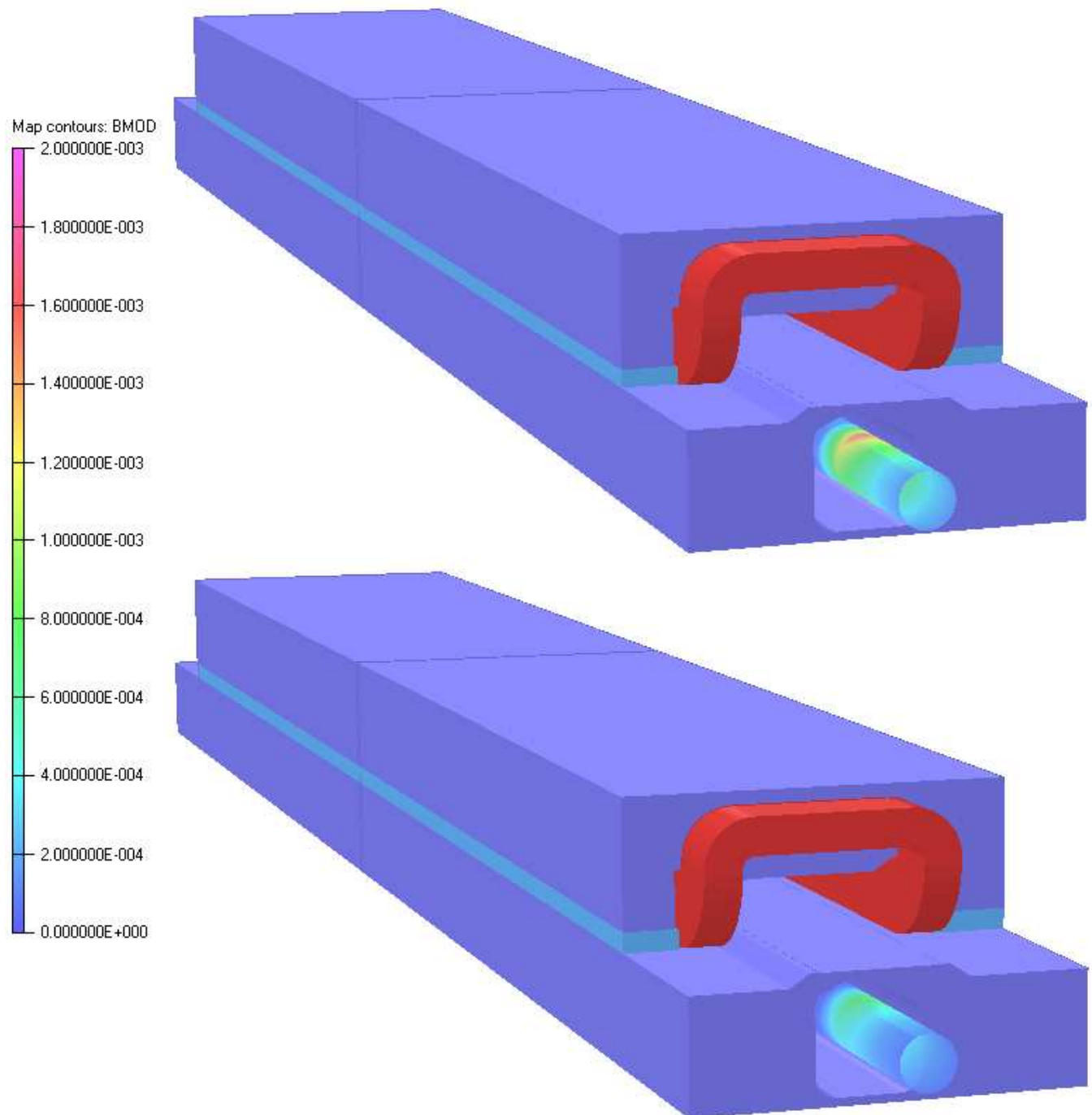


Figure 5 – Total field distribution for the old (upper) and the new (lower) configurations.

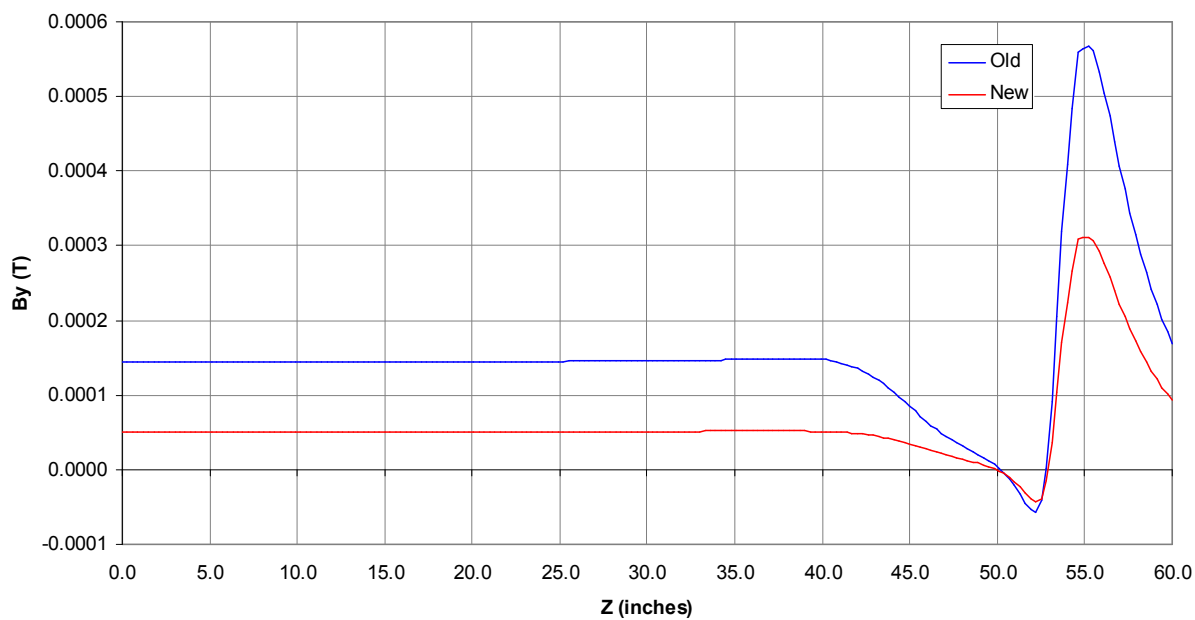


Figure 6 - By field component distribution along the longitudinal axis.

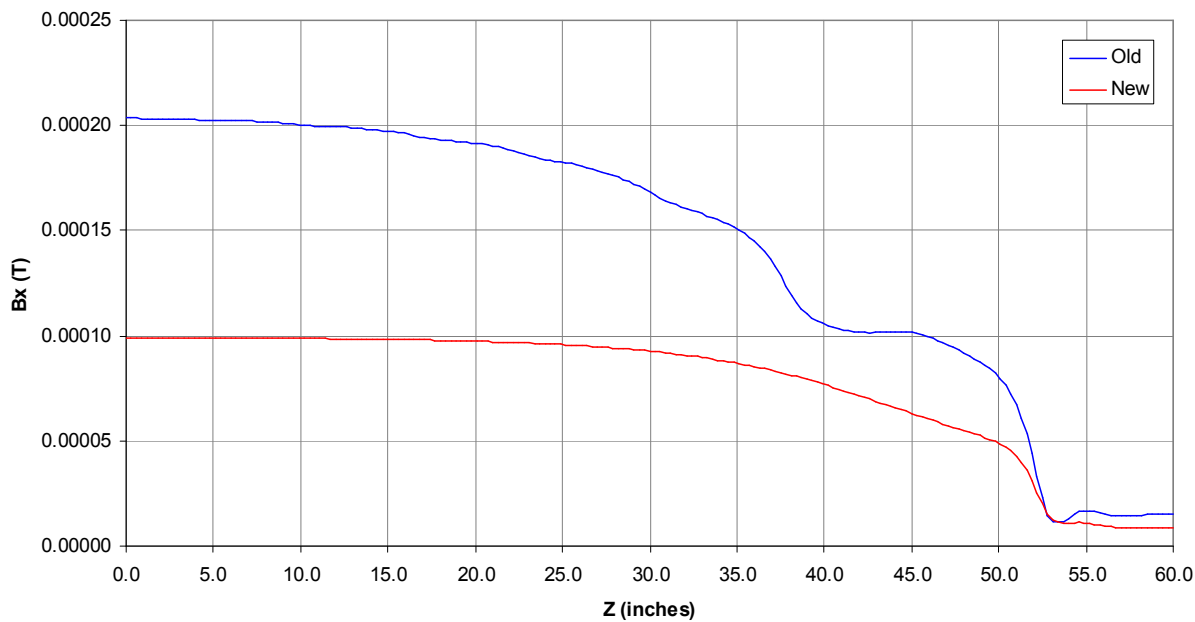


Figure 7 - Bx field component distribution along the longitudinal axis.

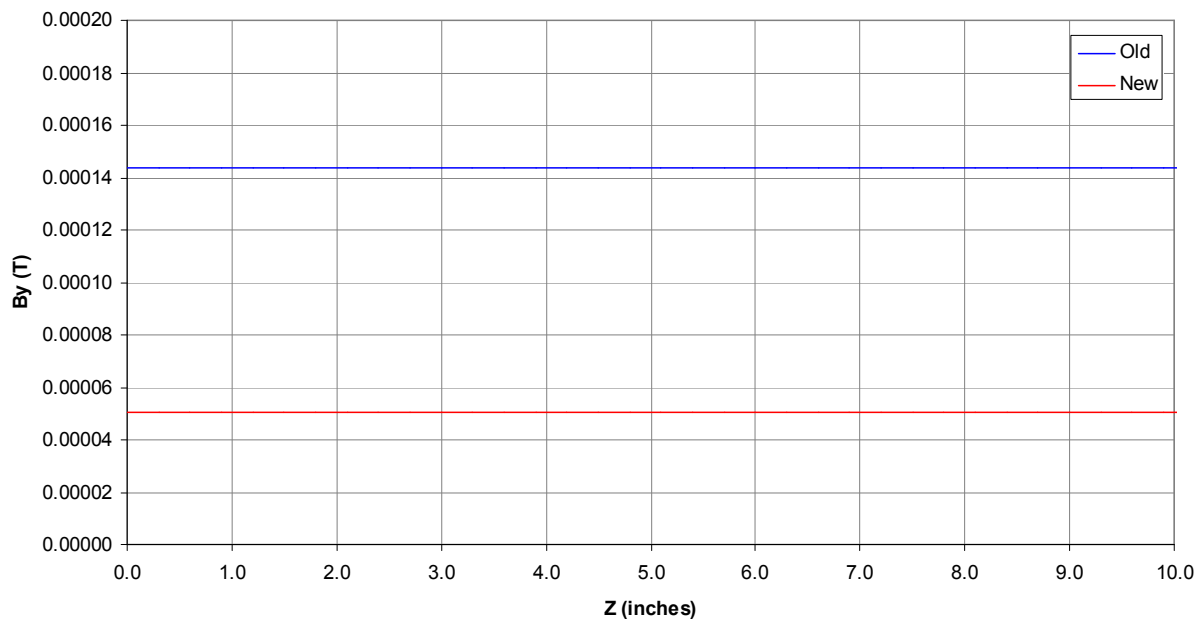


Figure 8 - By field component distribution along the longitudinal axis (zoom in).

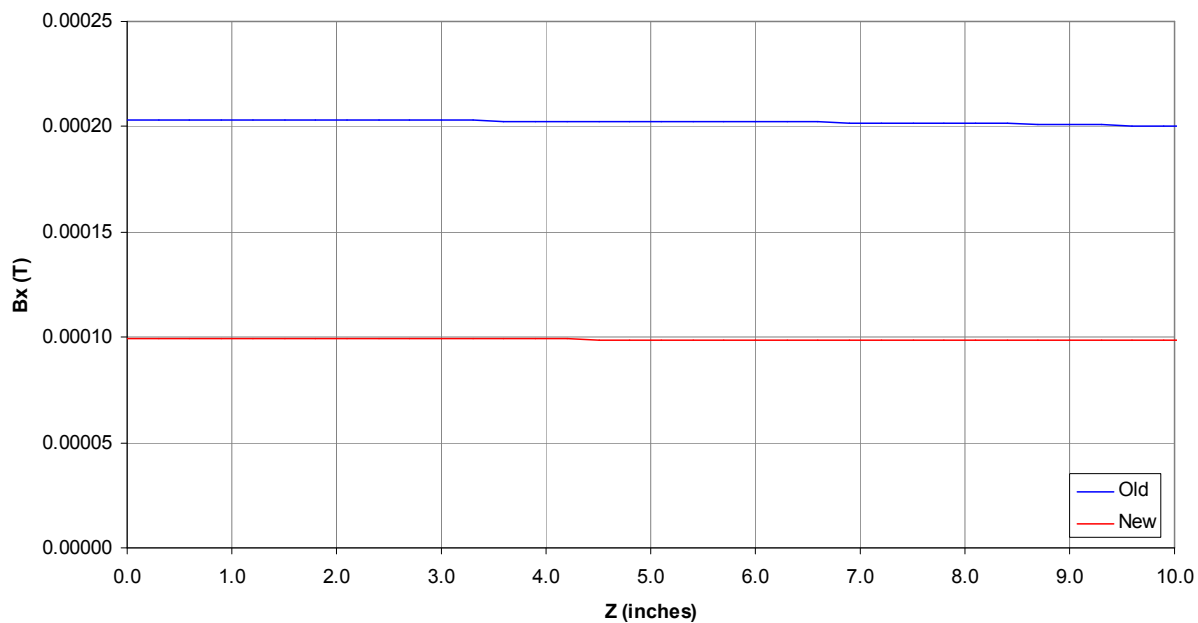


Figure 9 - Bx field component distribution along the longitudinal axis (zoom in).

Figures 10-11 show the gradient distribution along the longitudinal axis. The gradient could have an important role in the circulating beam [3].

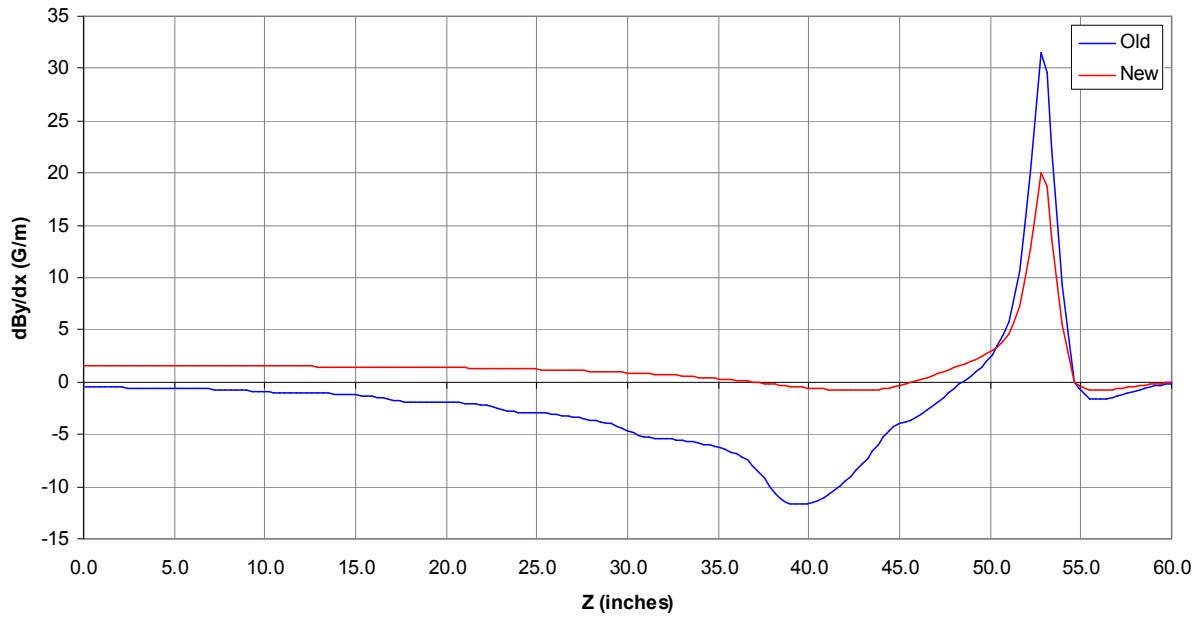


Figure 10 – dB_y/dx along the longitudinal axis.

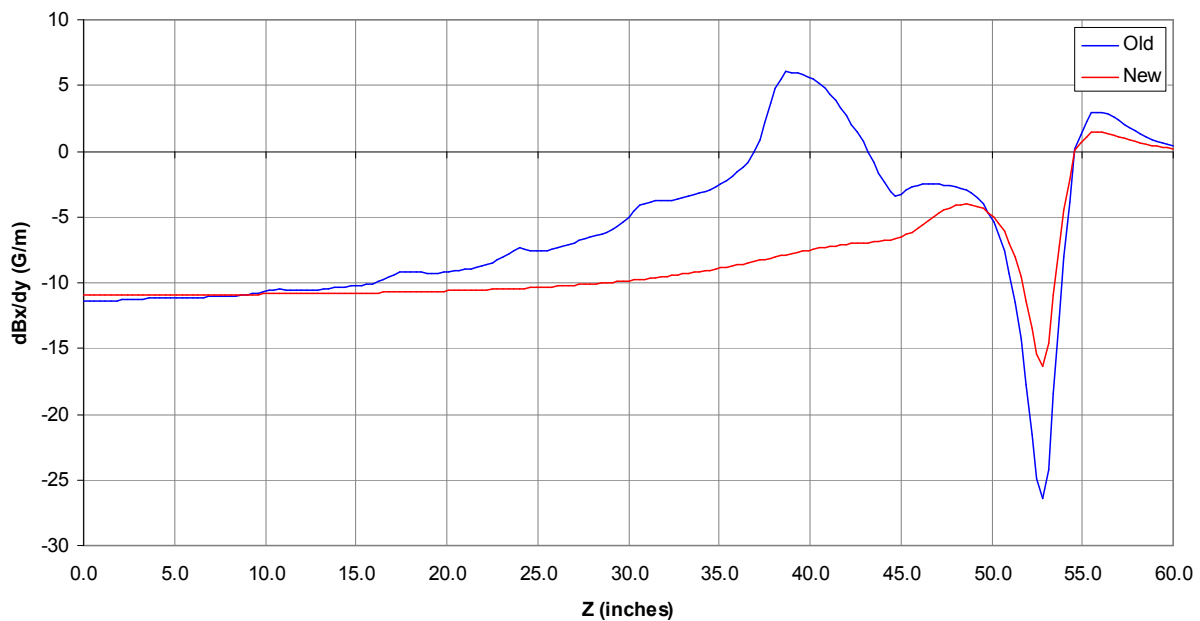


Figure 11 – dB_x/dy along the longitudinal axis.

3.2 Transverse

The total field distribution in a circle that covers, approximately, the circulating beam region is shown on Figure 12. As can be seen there is a significant reduction in the field in the center of the magnet.

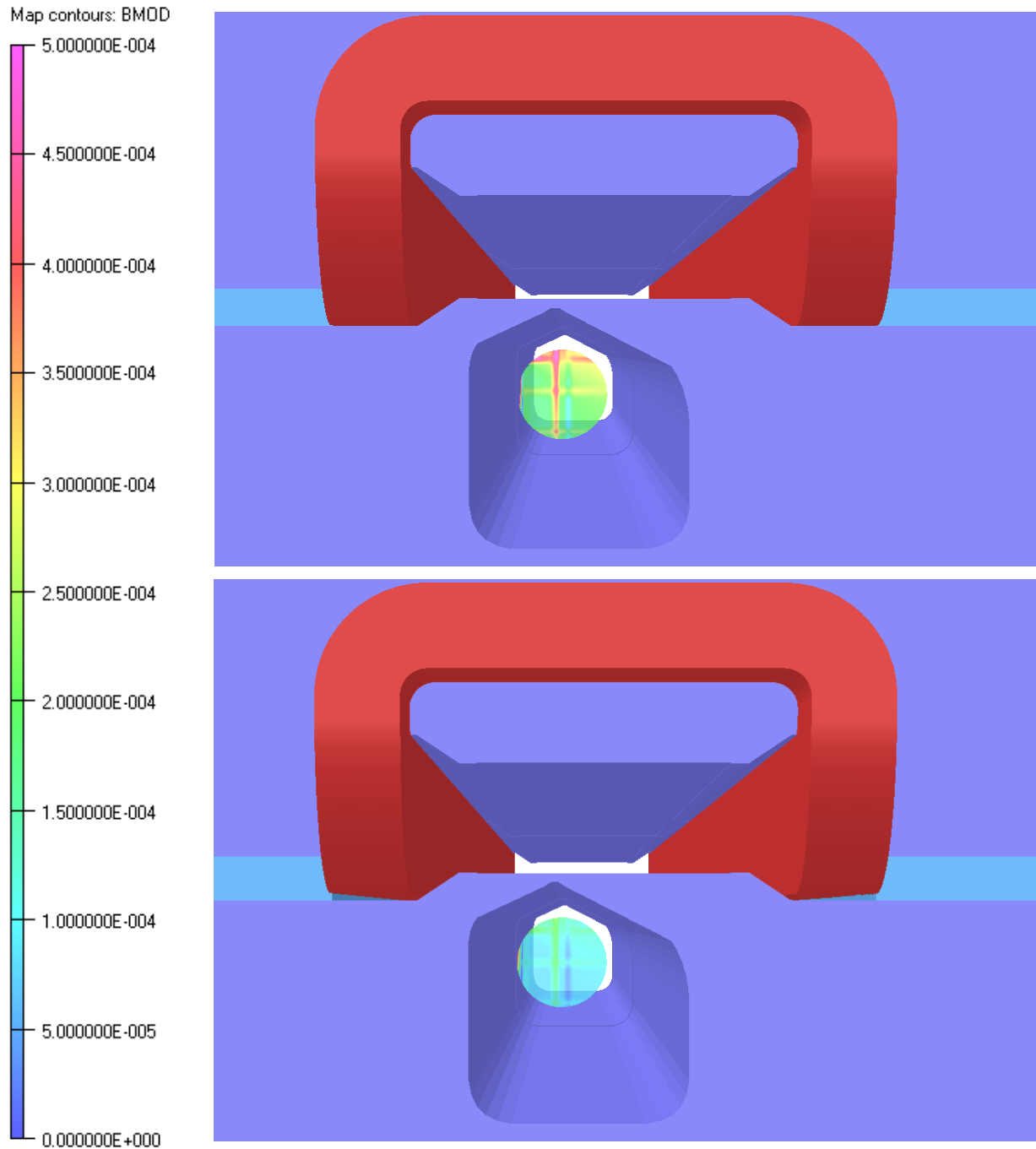


Figure 12 - Total field distribution in the center of the magnet in the old (upper) and the new (lower) configurations.

4 Conclusion

The MLA (old) and the modification for the MLAW (new) magnets were modeled in OPERA3D.

The analysis of the inter-pole region revealed that the increment of the effective length is about 2.5 mm. The field uniformity is slightly decreased in the new case due to the gap opening.

The analysis of the field-free region revealed that there will be a reduction of up to 50% of the total integrated field.

References

- [1] O. Kiemschies – Private communication
- [2] D. Johnson - Accelerator and NuMI Upgrade - <http://nova-docdb.fnal.gov/>
- [3] D. Johnson – Private communication